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RELATION BETWEEN IRRIGATION ENGINEERING AND BILHARZIASIS *

JOSEPH N. LANOIX, C.E., M.S.S.E.
Sanitary Engineer, Division of Environmental Sanitation, World Health Organization, Geneva, Switzerland

SYNOPSIS

The author discusses the relation between irrigation systems and the transmission of bilharziasis, with special reference to the important part the irrigation engineer can play in checking the spread of the disease. He points out that, in the past, there has been little co-operation between health departments and public works agencies in respect of the setting-up of irrigation systems, and stresses the advantages to be gained from an active collaboration between malacologists, epidemiologists and irrigation engineers at the planning stage of irrigation schemes.

The author also puts forward some suggestions for research on irrigation-system design and outlines the role of WHO in bilharziasis control.

" The introduction or development of irrigation schemes, as well as the change from basin to perennial irrigation, has always resulted in a considerable increase in the incidence and intensity of bilharziasis wherever that infection existed or was introduced by outside labourers. The severity of the infection may be such as to cause the abandonment of an irrigation scheme created at considerable expense." Such is the strong statement made in its first report (1950) by the Joint OIHP/WHO Study-Group on Bilharziasis in Africa,[1] when stressing the relation between irrigation schemes and the spread of bilharziasis. In January 1950, the Executive Board of WHO, at its fifth session, adopted the following resolution (*Off. Rec. Wld Hlth Org.*, 1950):

" Considering the danger to health entailed by the establishment of irrigation schemes in areas where bilharziasis is present, if the necessary sanitary precautions are not taken at all stages of the development of the schemes,

REQUESTS the Director-General

(*a*) to call the attention of governments and of the appropriate bodies and specialized agencies of the United Nations interested in irrigation to such danger and to the safeguards recommended by the Joint OIHP/WHO Study-Group on African Schistosomiasis; and

(*b*) to make appropriate arrangements to provide the said governments and organizations with the technical advice which they may require."

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[1] Formerly entitled " Joint OIHP/WHO Study-Group on African Schistosomiasis ".

It is apparent that, three years later, this warning had not been well heeded, as observed by the WHO Expert Committee on Bilharziasis, which stated in its first report (1953):

> " In spite of the formal cautionary notice issued by WHO to all governments and interested governmental agencies, on the risk of introducing or increasing the intensity of bilharziasis as a result of irrigation schemes, it is obvious that co-operation between health administrations and the authorities responsible for irrigation has not in many areas been achieved or been as close as was necessary."

The Committee also recommended, among measures designed to ameliorate the efficacy of snail control measures, that stress be laid on environmental control, i.e., drainage, irrigation, vegetation clearance, agricultural practices, and sanitation.

For the benefit of the engineers who may read this paper, it will be briefly recalled that bilharziasis (schistosomiasis) is a debilitating disease of considerable economic importance to more than 100 million people in the world. Water becomes contaminated with *Schistosoma* eggs which are passed by infested persons in faeces and urine. The embryo (miracidium) which is released from the egg can live up to 48 hours and must find an entrance into an appropriate freshwater snail. After a period of about six weeks, "cercariae" worms (about 0.3 mm long) emerge from the snail as free-swimming organisms and attack man in water (they are capable of penetrating the unbroken skin), causing a new infestation.

In spite of the importance of the relationship between irrigation engineering and agricultural practices and the spread of bilharziasis, very little effective action has been taken in the past by either public health or public works authorities in most countries affected. In fact, very little is known today of several aspects of snail ecology and of the effects of irrigation factors on the growth, survival and multiplication of disease-carrying snails. On the other hand, irrigation engineers are generally not trained to understand and take into consideration the health aspects of irrigation schemes, in spite of the fact that they aim at increasing the welfare and economic level of whole populations.

It is a well-known fact that in many countries, for example, the USA and India, where irrigation engineering practice is highly developed, bilharziasis has never been a serious problem, although swimmer's itch (caused by *S. cercariae*) and malaria are sometimes of serious concern. In these circumstances, great emphasis has been placed by engineers on water and land management, especially the management of excess irrigation waste-water that has resulted from surface run-off and seepage.

In other countries which are striving to augment their food supplies by bringing new land under irrigation, bilharziasis and a host of other communicable diseases assume major importance. Such is the case in many areas of Africa, the Middle East and the Western Pacific. In a personal communication to WHO, D. M. Blair recently drew attention to the following statement made in the 1953 annual report of the Department of Health for Southern Rhodesia (1954):

> " Despite continual advice given by the Health Department, irrigation schemes are planned and developed without due consideration of the health aspects. There is absolutely no doubt that every irrigation area in the Colony will become infested with vector snails which will eventually become infected with bilharziasis unless the danger is realized at the outset, and plans for prevention made. The statement has been made before, and must be made again, that large scale irrigation schemes may well wreck the health of the country and bring the most grandiose schemes to a pitiful end. So many people see only the economic advantages of irrigation, and refuse to recognize the great disadvantages inherent in such schemes if adequate precautions are not taken *from the outset*."

He also reports that one of the first irrigation schemes established in that country after the Second World War has been a complete failure and is now largely abandoned because malaria and bilharziasis were left out of the calculations.

A striking example of such a situation is given by Khalil (1949) in connexion with the scheme for the perennial irrigation of four areas in the Quena and Aswan provinces of Egypt. Irrigation engineers disputed this relationship for some time, until conclusive evidence developed when these areas were carefully surveyed, three years after the introduction of irrigation. The following increase in bilharziasis prevalence was noted:

	Percentage of population infected	
	1934	*1937*
Sibaia	10	44
Kilh	7	50
Mansouria	11	64
Binban	2	75

The author also stated that " since the erection of the Asswan Dam and the introduction of perennial irrigation into most of the provinces of Egypt, bilharziasis spread out and the health and mentality of the individual deteriorated ".

The importance of irrigation in the spread of this disease is also stressed by other experts. Mozley (1953) considers that irrigation is " probably the most menacing feature of the development of the bilharzia problem " in Africa. Scott, cited by Abdel Azim (1948), was also " impressed by the fact that where schistosomiasis is a primary problem, it is associated with irrigation and other artificial environments created by man ", and he added that: " In Venezuela and in places I have visited in Brazil, I am certain these environments could be made unfavourable to the snail at no great cost and without destroying the usefulness of the water resources for man."

Like Blair, Watson (1950) expressed deep concern regarding the possible spread of bilharziasis to virgin land areas, when, speaking of Iraq, he wrote:

" The vast new irrigation schemes that have been planned and are in some cases already under construction (November 1950) will, however, inevitably add to the extent and gravity of the problems of bilharziasis in Iraq. The enormous areas of barren but potentially fertile land which will thus be brought under cultivation in the central and southern provinces will certainly become bilharzial endemic areas unless adequate steps are taken to prevent the spread of the snails into the new irrigation systems and to stamp them out rapidly whenever they appear."

The propagation of the disease has also been associated with irrigation schemes in Algeria, China, Japan and to a minor extent in the Philippines, although the molluscan intermediate hosts of the disease are not always the same in every country.

Irrigation systems have also been incriminated by epidemiologists and other health authorities of conveying the causal agents of several other diseases of man, such as enteric bacterial infections, diarrhoeas, cercarial dermatitis, guinea worm, poliomyelitis and, possibly, histoplasmosis. Animals may also be affected by such diseases as fascioliasis. Irrigation systems provide suitable breeding-places for some dangerous insect vectors of disease, such as certain species of *Anopheles*—the vectors of malaria—and mosquito vectors of dengue, filariasis and encephalitis.

Principal Engineering Features of Irrigation Systems

From the brief account given above, it will be noted that public health authorities and malacologists in particular have, in several instances, pointed an accusing finger at the so-called culprit, i.e., the irrigation engineer, while recognizing at the same time the merits of his work. It might be interesting, before proceeding further with the health aspects of the subjects, to try to understand this engineer's problems and difficulties.

First and foremost, the irrigation engineer is concerned with bringing water to thirsty lands in order to make them productive, at the lowest possible cost. While doing so, he designs his structures and attempts to manage the precious liquid at each step in the intake and conveyance process in order to supply to the land and the crops the precise amounts required for efficient agriculture. His next worry is the removal of excess irrigation water and, sometimes, the lowering of the ground-water level in order to avoid waterlogging and to prevent the topsoil from becoming impregnated with harmful mineral salts.

The systems which he uses to achieve his purpose include:

1. *Diversion works.* These range from a simple intake structure built on a natural stream to most elaborate works comprising the erection of dams, headgate, sluice gates, regulation works, and miscellaneous structures necessitated by the conversion of part of a watershed or valley into water storage reservoirs.

2. *Pumping stations* for drawing ground water for irrigation or for boosting the water level and increasing the land acreage which may be served.

3. *Conduits* for conveying water from the place of diversion to farm furrows. The term covers canals (lined or unlined), flumes, pipes and tunnels, as well as auxiliary structures such as drops, waterways, and turn-outs and canal crossings.

4. *Distribution systems*, comprised of laterals and ditches, for conveying water from the main canal to each parcel of land to be irrigated.

5. *Drainage works*. This term covers the construction of ditches, tiles, and pumping stations.

6. *Levees*, for preventing the entrance of outside water on irrigated lands subject to overflow.

It appears that the study and care of the above works, coupled with that of their economic and legal features, preoccupies the irrigation engineers to such an extent that they are inclined to give too little attention to the health implications of their work. This is perhaps an exaggeration, but the fact remains that, in most countries where irrigation water is implicated directly or indirectly in the transmission of disease, there is little, if any, co-operation between health authorities and irrigation or public works agencies.

It is not possible within the scope of this paper to review in detail the engineering features of each of the structures listed above or to analyse fully their potential relationship to factors bearing upon the transmission of bilharziasis. As an example, however, it is proposed to discuss the design and operation of open channels, chiefly laterals, which are most often responsible for the growth and multiplication of the molluscan intermediate hosts of bilharziasis.

Main Elements in Design of Irrigation Channels

Velocity

The velocity at which the water flows depends on the steepness of the canal slope, the size and shape of the channel, the roughness of its perimeter and the viscosity and density of the water. Irrigation channels are designed to carry water at the highest velocity that can be maintained without erosion, due consideration being paid to the extent of the land area to be served. This is the most economical velocity, since it results in practice in the smallest canal section and the lowest construction cost while permitting a minimum deposition of silt. Few natural materials will stand velocities in excess of 5 feet (1.5 m) per second, while lined canals may be designed for velocities as high as 10-12 feet (3.1-3.7 m) per second, depending upon the nature of the lining material used.

These figures are for mean velocity in a channel. It should be noted, however, that the actual velocity varies throughout the water prism in some manner that depends on the conditions of flow. The mean velocity is normally 0.9 times the maximum and occurs about 0.577 d from the surface, where d is the depth of water in the canal. The bottom velocity averages perhaps half the maximum. Similarly, marginal velocity is considerably smaller than the velocity at the middle of the stream.

Marginal and bottom velocities are further reduced by aquatic vegetation. Malacologists have often indicated that snails do not multiply in swift-flowing channels and believe that the velocity of the water is the governing factor. On the other hand, snail colonies are likely to be found when the current slackens or when the banks and side slopes are covered with vegetation.

Another factor that contributes to a reduction of the velocity for which a canal has been designed is the fact that water may be drawn off in varying amounts and at various points along the canal. It may also happen that water is left standing in canals at times when it is not needed for crops. Of course, when the layout of the irrigation system has been well planned and executed, with the actual participation of local agricultural authorities, such situations are less likely to arise and it is possible for the engineer to design each canal section for expected high as well as low flows and for a given minimum velocity. It is difficult to foresee, however, all the situations which may confront the agriculturist in the future and which may have a bearing upon conditions of flow in canals long after these have been built by the irrigation engineer.

When drawing up his plans, the engineer is often subjected to pressure by interested groups—agricultural authorities, land-owners, etc.—to flatten the slope of large canals and laterals in order that these may command and serve the greatest cultivable area possible. If he yields to such pressure, he is forced, in order to transport the designed flow of water, to reduce the velocity and increase the cross-section of the canals, which may no longer be the most economical to build.

The question arises in the mind of the engineer as to what is the minimum velocity that will prevent the establishment of snails in canals. The full answer to this question, which is more complex than it appears on the surface, is apparently unknown at present.

The deposition of silt in a canal, whether the latter be unlined or lined, is troublesome because it reduces the cross-section of the canal and, even in a lined canal, creates suitable conditions for the growth of aquatic plants on which snails can rest. On the other hand, the engineer must also consider the fact that the erosive action of water on earth banks is actually decreased by silt in suspension. It is necessary for him to choose a velocity that will keep the silt in motion but that will not erode the bank of the canal. The silt content of irrigation water may vary with the season, and its nature (whether abrasive or colloidal) depends on many factors. The determination of non-scouring and non-silting velocities for canals with earth banks has been attempted by many investigators. Fortier & Scobey (1926) give the following permissible velocities in canals excavated through different soils:

Materials excavated for canals	Velocity (feet per second), after aging, in canals carrying clear water (no detritus)	water containing colloidal silts	water containing non-colloidal silts, sand or gravel
Fine sand, non-colloidal	1.50	2.50	1.50
Sandy loam, non-colloidal	1.75	2.50	2.00
Silt loam, non-colloidal	2.00	3.00	2.00
Alluvial silts, non-colloidal	2.00	3.50	2.00
Ordinary firm loam	2.50	3.50	2.25
Volcanic ash	2.50	3.50	2.00
Fine gravel	2.50	5.00	3.75
Stiff clay, very colloidal	3.75	5.00	3.00
Graded, loam to cobbles, non-colloidal	3.75	5.00	5.00
Alluvial silts, colloidal	3.75	5.00	3.00
Graded, silt to cobbles, colloidal	4.00	5.50	5.00
Coarse gravel, non-colloidal	4.00	6.00	6.50
Cobbles and shingles	5.00	5.50	6.50
Shales and hardpans	6.00	6.00	5.00

On the other hand, Kennedy (1895) gives the following formula for the determination of a velocity that will neither silt nor scour: $V_0 = C\, d^{0.64}$ where d is the depth of the canal, in feet, and C is a coefficient whose value depends on the fineness of the soil particles. For the sandy silt of the Punjab, Kennedy suggested a value of 0.84 for C. For the extremely fine soils in Egypt a value of 0.56 has been found. For coarse silt, C may be as high as 1.0. Several other formulae have been suggested, but the final solution of this important problem is not in sight. At present it is considered that a safe design will result if maximum velocities are determined from Fortier & Scobey's table and minimum velocities for silty waters from Kennedy's formula.

Hydraulic shape and depth

Because the wetted perimeter of canals offers frictional resistance to flow, it is desirable that it be kept to a minimum. Canals, especially earth-made, are most often trapezoidal in shape. The most efficient trapezoidal section has side slopes of 60 degrees, which is usually too steep for earth canals. On the other hand, the most economical cross-section under favourable structural conditions is, according to Israelsen (1950):

$$b = 2d \tan \frac{\theta}{2}$$

where b is the bed width, d is the depth of the canal (unlined or lined), and θ is the angle of the side slope with the horizontal.

Canals can also be designed with a rectangular cross-section, in which case the most efficient section would have a depth equal to half its width. At each step of canal design, the irrigation engineer is most concerned with finding the cross-section that has the best hydraulic shape and properties and is the most economical to build. The sides of earth canals are normally constructed as steep as the earth will permit when wet. The slope of the sides varies from 3 horizontal and 1 vertical to 1 horizontal and 1 vertical for very stable materials.

The depth of water is usually not a critical element in the design of irrigation channels. However, in large earth canals it is necessary to limit the depth to protect high embankments against water pressure and to reduce the danger of an embankment failure. Consequently, depths in excess of about 10 feet (3 m) are usually avoided.

From the standpoint of snail control, it would apparently be desirable for canals to be provided with vertical sides and the maximum possible depth. These factors would have the effect of discouraging both marginal and bottom vegetation and of reducing the penetration of light. A canal with vertical sides would, of course, have to be lined, and this, for the irrigation engineer, means increased costs and a totally different design. Thus, it can easily be seen that the points of view of engineers and malacologists are sometimes quite divergent. Would the engineer be justified in making such a radical modification in his design for the sake of controlling snails and bilharziasis, and perhaps other diseases ? Another question to which the engineer would like to know the answer is what combination of depth and turbidity of water is necessary to prevent aquatic vegetation of the type favoured by snails.

Conveyance losses and canal lining

Conveyance losses from all forms of conduits usually employed are inevitable and are caused by leakage, seepage, evaporation and transpiration.

It has been estimated in the USA that " one-third to one-half of all the water diverted for irrigation is lost before it reaches the farmers' fields " (Rohwer, 1946). The greatest losses are due to seepage and occur in unlined earth canals. Losses caused by evaporation and transpiration are largely unavoidable under normal conditions of operation and those due to leakage depend on the conditions of irrigation structures. Seepage loss from unlined canals, however, usually decreases with the age of the canal, particularly if the water carries silt.

The engineer is greatly concerned with these conveyance losses and will do his utmost to reduce them. The simplest and most effective way of minimizing such losses is to line the canals—a proceeding which will save both water and land. Methods of lining and the economics of the process will be discussed later. The important and gratifying thing to note here is the fact that malacologists and irrigation engineers will readily agree as to the beneficial effects of canal lining. To a greater or lesser extent, depending on the type of lining, the malacologist can expect a reduction in water-plant growth, an increase in the velocity of the water, a reduction in canal cross-section and a reduction in the amount of plankton and decaying matter to serve as snail food, all of which combine to make an environment unsuitable for the development and multiplication of snails.

Irrigation Systems as Habitats of Disease-carrying Snails

Irrigation structures

Irrigation systems, from intake structures and reservoirs to the farmers' furrows, offer countless opportunities for the growth and multiplication of various types of snail. In Egypt, Barlow (1937) stated that the optimum environment of both *Planorbis boissyi* and *Bulinus truncatus* comprised fairly clean water with some flow but not too deep or swift, plant litter, sunshine and shade, good places for egg-laying, few natural enemies and an undisturbed situation. *Bulinus* has also been found at the bottom of irrigation canals, clinging to weeds, since it needs much oxygen.

In Iraq, Watson (1950) found that the habitat of *Bulinus truncatus* in irrigation systems consists of a more or less permanent collection of stagnant or slow-moving water, associated with a certain degree of pollution, especially from human wastes. He also found that water-plants and mud rich in decaying matter appear to be a usual but not an essential characteristic of its habitat, and that decaying vegetation and unicellular algae are used as food. Other disease-carrying snails which breed in irrigation channels and reservoirs include *Biomphalaria pfeifferi* (in marshy areas and on the banks of channels with vegetation), *Bulinus (Physopsis) globosus* (on the marshy shores of reservoirs, and in rice-fields and ditches), *Oncomelania nosophora* (in irrigation channels in Japan and China) and *Australorbis glabratus* (in open sewers in Brazil).

It should be noted that certain parts of an irrigation system may be more suitable than others for the development of snails. These conditions have been studied in some detail by Mozley (1955) in connexion with ponded areas (or reservoirs), sites below dam walls, main earth canals, secondary and tertiary earth canals, small channels, fields and gardens, tail pools, etc. He noted, in particular, that large canals seldom offer suitable habitats for snails because of the rapid and continuous flow of water. On the other hand, secondary and tertiary canals are often very dangerous sites of infection with *Schistosoma*. The same phenomenon has been observed by several other investigators, who have also found that canals lined with cement, stone or brick are usually unsuitable for snail breeding, except where silt deposits permit the growth of water-plants.

In unlined canals, snails are able to bury themselves or are stranded in the bottom mud and survive for several months when irrigation is suspended and the canals are dried out. This is especially true in irrigated areas where the ground-water level is sufficiently high to keep the earth layer at the bottom of the canals in a moist and cool condition. Clay bottoms, however, do not appear favourable to certain types of snail. In concrete or similarly lined canals, snails are unable to dig in and they and their eggs are killed by desiccation and the heat of the sun. These facts are extremely interesting to public health and irrigation engineers, who see in them the important roles played by water velocity and hard-type canal lining in the multiplication and survival of snails.

Impounded reservoirs seem to offer environmental conditions which may be suitable for certain snails and not for others. A typical example is the Sennar reservoir in the Sudan. In this reservoir, *Bulinus* is very common and *Planorbis* absent, while in the canals served by it both species are found side by side. It has also been observed that variations in the water level of impounded reservoirs, which are often created for mosquito control, have a definite effect on the survival of snails and their eggs. Decaying vegetation in such reservoirs and aquatic plant growth along the margins provide food for certain snail species, while irregularities in the marginal lake contour are likely to afford shelter against wind, waves and water current. At certain seasons, pollution of the top water layers with the products of vegetation decay and the presence of plankton may be more pronounced than at others, owing to churning currents, which are set in motion by changes of the surface temperature. In impounded reservoirs, schistosome-carrying snails of the genera *Biomphalaria* and *Bulinus*, as well as snails of the genera *Lymnaea* and *Physella* responsible for schistosoma dermatitis infection, may be found in addition to various species of harmless snails.

Observations have also been made by some investigators as to the mode of entry of snails into irrigation systems. Sometimes intakes are mere diversions of water from infested streams, in which cases snails are simply washed down the irrigation system or are carried on floating debris or vegetation, especially at times of flood. The same situation prevails when water is taken from the top of reservoirs. In North Africa, F. G. Marill (personal communication to WHO, 1955) noted that snails were able to penetrate the openings of intakes located far below the surface of reservoirs. In one instance, he even found snails in an irrigation works fed from infested streams through turbine pumps operating at 600-800 revolutions per minute. In this case, however, he could not ascertain whether the snails survived the churning motion of the turbines at the adult or at the egg stage.

It might be interesting for the engineer to know that the length of schistosoma-carrying snails does not exceed 2.5 cm, being usually between 1.0 cm and 1.5 cm. Their "width" is usually from 0.4 cm to 1.2 cm, approximately. These data rule out screening as a practical means of keeping snails out of irrigation channels.

Culverts and canal crossings which are poorly designed and built, and pools of water that collect at the bottom of earth channels or in borrow-pits, are frequently dangerous sites of *Schistosoma* infection under certain conditions. In arid areas, such water may frequently be used by nomads and neighbouring populations, owing to the scarcity of other suitable sources of water for drinking and other domestic purposes.

Effect of water quality

Generally speaking, water which is good for irrigation is also good for snail development. The irrigation engineer is concerned primarily with the amount of dissolved salts, of which the most important are the bicarbonate, sulfate and chloride of calcium, magnesium and sodium. The total concentration of dissolved salts in water used for irrigation purposes is usually between 100 and 1500 parts per million (p.p.m.). Occasionally, water of higher salt content will be employed on more tolerant crops. Minor constituents include boron, silicate, nitrite, sulfide, phosphate, iron, aluminium, ammonia, hydrogen ion as measured by pH and organic matter. These constituents are usually present in low concentrations in natural waters and, with the exception of boron, are not of great importance in their relation to the soil or to plants (Wilcox, 1948).

The presence of calcium salts and of nitrite, sulfide and ammonia, however, may be of great importance to the malacologist, who is aware of the fact that snails need calcium for the growth of their shells and thrive in waters polluted with moderate, but not excessive, amounts of the intermediate products of decomposition. In fact, in Iraq and Southern Rhodesia, it has been observed that the best sites for infection by cercariae and the most suitable habitats for snail colonies are those portions of the irrigation laterals which are located within a few hundred metres of villages and settlements and which are polluted by human faecal and other wastes. The use of urban sewage for crop irrigation, although desirable under certain conditions, would probably be conducive to an environment suitable for snail development.

The total concentration of salts in irrigation water seems to have a direct effect on the survival of snails. This aspect, which had long been neglected by malacologists, has been studied by Watson (1950) in connexion with the schistosome-carrying *Bulinus* snail in Iraq. He found that "the maximum salinity which has been correlated with the presence of *Bulinus* in natural waters in Iraq is 1010 p.p.m.", although in the laboratory the snail survived in water containing 1500 p.p.m. and might stand still higher salinities " if gradual acclimatizations take place ". However, he also stated that a concentration of 4000 p.p.m. would be instantly fatal to the snail. Further research is needed to find out the effect of salinity on other vector snails under various environmental conditions. To the irrigation engineer and the agriculturist, water containing more than 2100 p.p.m. dissolved salts would be considered unsuitable for agriculture. So would water with an electrical conductivity greater than 3000 micromhos per cm and a percentage of sodium over 80.

Another factor of apparent importance to snails is the acidity of the water. Information available indicates that snails prefer slightly alkaline water with a pH above 7.3, a condition which is often met by natural surface waters, especially in arid areas. This is also a subject which requires more research but which is not likely to be of direct concern to the irrigation specialist. It is worth mentioning that Deschiens and some other investigators have recently been paying much attention to the influence of water quality on the growth and survival of snails (Deschiens, Lambault & Lamy, 1954; Deschiens & Lamy, 1954).

Weed growth in irrigation canals

The growth of water-weeds presents a serious problem to everyone concerned with an irrigation system. In severe cases, it may be responsible for a low yield or poor quality of crops since it interferes, directly or indirectly, with delivery of water. Water-weeds also reduce the capacity of canals, prevent the regulation of flow, clog irrigation structures and drains, and reduce the velocity of flow, thus permitting the deposition of silt. In addition, they are responsible for a considerable increase of water losses through seepage and transpiration. This situation is at its worst during the warm season, when irrigation water is most needed for agriculture.

Like the farmer and the irrigation engineer, the malacologist is vitally interested in getting rid of aquatic plants wherever " irrigation " bilharziasis is present. As indicated before, aquatic plants help to create an environment suitable for disease-bearing snails, as well as providing the snails with shelter and with some of the oxygen that they require. There are three main types of water-weeds: floating, submerged and emergent weeds. Species of plants vary from country to country and from one area to another. Methods of control will be briefly outlined later.

The Role of the Engineer in Bilharziasis Control

As pointed out previously, nowhere in the world has there in the past been much, if any, co-operation between the bilharziasis control services of the ministries of health and the irrigation departments of the ministries of public works. As a result, in countries where bilharziasis is endemic health departments are usually faced with a tremendous problem and the need for heavy expenditure of public funds on temporary and recurrent control measures by the use of chemicals. The control problem would be so much simpler and cheaper in the long run if only an active and effective collaboration prevailed between all interested government services at the planning stage of irrigation schemes.

An obvious method of achieving such collaboration would be for health departments to include engineers in their bilharziasis control units. In several countries where this disease constitutes a most serious public health problem and where engineering is called upon to play such an important role in the planning and execution of control measures, it is rather surprising that no engineers have been incorporated in bilharziasis control teams. Civil and irrigation engineers could easily be given a short course and a period of in-service training in bilharziasis control units, in order to prepare them for their role. Public health engineers, whose basic training is in civil engineering, would be of immense value as full members of bilharziasis control teams. The role of the engineer would consist primarily in establishing and maintaining technical contact with his public works colleagues, in participating in the planning and design of both irrigation schemes (at the public works department) and bilharziasis control schemes (at the public health department), in following up the construction and layout of irrigation projects and, finally, in carrying out or supervising the application of sanitation and bilharziasis control measures, whether by engineering or by chemical means.

Control Methods Applicable by the Engineer

Having reviewed the engineering features of irrigation systems and the role of the latter as habitats of the molluscan intermediate hosts of the disease, it is pertinent to consider the methods and tools which may be employed by the engineer in an attempt to render the irrigation environment unsuitable for the growth or migration of snails. Such a study is difficult to make, however, since the subject has long been neglected and since few, if any, investigations have ever been carried out in the field to determine practical engineering means of reducing the transmission of bilharziasis through improvement of irrigation systems. The problem is further complicated by the fact that a thorough understanding of the basic phenomena of snail ecology is so far lacking and that, as a result, health authorities themselves have not been able to promulgate precise rules and criteria for the guidance of the engineer. At this time, it is only possible to review briefly several of the methods already in use to improve and maintain irrigation systems and to study the feasibility of their application, perhaps in modified form, to the control of bilharziasis vector snails. The following review is far from complete, but it is hoped that its presentation, though imperfect, will stimulate active experimental work and research on the subject.

Impounded reservoirs

The following measures might be applied:

(*a*) Removing vegetation and weeds from banks and shallow margins.

(*b*) Clearing reservoir's site of vegetation and submerged weeds down to an appropriate depth (possibly 6 feet).

(*c*) Deepening and straightening shallow reservoir margins (to what depth ?).

(*d*) Varying the water level, a well-known method used for mosquito control. For bilharziasis control, however, it is possible that the difference in levels and the time intervals between fluctuations will need to be greater.

Channel training and maintenance

(*a*) Cleaning and re-grading canals. In several countries where labour is relatively cheap, this is done year after year to improve temporarily the hydraulic properties of earth canals and eliminate dead water, shallow eddies and bottom pools. However, it does not prevent or reduce snail growth and does not eliminate aquatic vegetation, which grows quickly again to the point of completely choking the canals.

(*b*) Straightening canals, to eliminate unnecessary bends and increase both slope and velocity of flow.

(*c*) Back-filling unused canal branches, borrow-pits and neighbouring low ground where seepage from irrigation canals might collect and form pools for snail breeding.

(*d*) Flushing canals at periodic intervals, a method sometimes used for mosquito control in open drains.

Weed clearance

(*a*) Hand and mechanical means of controlling emergent weeds (Young, 1954):

Scythes, sickles, etc.
Weed rakes
Cutters (drawn; propelled; launch-mounted and with moving blades)
Excavators (draglines and shovels with special buckets; bucket dredges; screw-type dredges)
Drying of canals and burning

(*b*) Hand and mechanical means of controlling submerged weeds (Young, 1954):

Flexible underwater saws
Chains
Scrapers (used in mortar-lined channels)
Cutters (usually with V-shaped blades; may be drawn, propelled or launch-mounted and with moving blades).

The above methods have been used extensively, sometimes with much success. However, in many cases they have been found to be time-consuming, cumbersome and expensive, in addition to being inefficient. At present, the control of water-weeds by chemicals is probably the cheapest method available. This aspect of the subject is, however, outside the scope of this paper.

Canal lining

There are various kinds of canal linings which may be classified according to the material used, as follows:

(*a*) Earth linings:

Thin or thick compacted-earth linings
Bentonite (an earth material containing a large percentage of montmorillonite clay)
Stabilization and compaction of clayey or granular soils
Resin and chemical stabilization
Soil-cement linings

(*b*) Asphaltic linings:

Asphaltic concrete
Buried asphalt membrane
Asphalt macadam
Other types of asphalt lining

(*c*) Plastic linings

(*d*) Stone, rubble masonry or brick linings

(*e*) Shotcrete linings

(*f*) Concrete linings:

Reinforced
Un-reinforced

Under the heading " Conveyance losses and canal lining " above, the advantage of linings in reducing seepage losses was stressed. For the engineer, other advantages are: reduction of friction losses; increased velocity; smaller canal cross-section for same flow; fewer and smaller structures; narrower right-of-way and hence saving of land; reduction or elimination of silt deposition and weed growth; easier cleaning and maintenance; protection against erosion; fewer drainage problems; and, finally, and of no less importance, reduction in total annual cost (US Department of the Interior, Bureau of Reclamation, 1952).

For the agriculturist, the chief advantages are: more water for crops; increased acreage of land which can be brought under cultivation; and protection of low lands from seepage and waterlogging.

The malacologist and the public health official, on the other hand, are not so much interested in canal lining *per se* as in the type of lining which should be employed. Most asphaltic and plastic linings require a covering of earth. Earth, asphalt and plastic linings will, indeed, improve the hydraulic properties of a channel, but they will not bring about any appreciable reduction of aquatic growth and, moreover, snails will be able to survive for months in bottom mud and cracks at times when the canals are empty. The prime interest of the above officials is in *hard-surface* linings, the best of which are concrete linings.

Under certain conditions and against certain species of snails, concrete has proved to be extremely effective. In the Fukuyama area of Hiroshima Prefecture in Japan, W. H. Wright (personal communication to WHO, 1955) was unable to find *Oncomelania nosophora* in concreted irrigation canals and believes that the concreting of the canals had much to do with the decline of bilharziasis in the townships of Mino, Miyuki and Akiya. He also observed that, in Santos, Brazil, *Australorbis glabratus* was sometimes present in open concreted sewers, but only in small numbers and mostly in places where vegetation had sprung up between cracks in the concrete and the flow of sewage was at a low level (which results in reduced velocity). Statements by D. B. McMullen (personal communication to WHO, 1955) confirm Wright's findings in Japan. F. G. Marill (personal communication to WHO, 1955), however, believes on the basis of his observations in Algeria that concrete linings would not prevent the establishment of stable colonies of *Bulinus*. But in Iraq, Watson (1950) found that stone, brick and cement-lined channels rarely offer a suitable habitat for *Bulinus* unless silt is allowed to deposit in them and aquatic vegetation to develop. More observations need to be made on this point with regard to different species of the molluscan intermediate hosts and under various environmental conditions.

Although the initial cost of concrete linings is relatively high, they are most desirable for the engineer because of their long life and minimum maintenance requirements. It is estimated that the average serviceable life of a good quality concrete lining is not less than 40 years. The use of modern equipment reduces appreciably the cost of canal lining, and the cost can be further lowered if the adoption of concrete lining is decided upon in the planning stage of new irrigation schemes.

In bilharziasis endemic areas, it would be highly advisable to provide the secondary and tertiary canals, where the snail problem exists, with hard-surface linings. However, restricting the lining to the portions of canals situated near communities may be desirable and more practicable. Main canals and the smaller distribution channels and furrows often need not be lined. In this matter, the engineer and the malacologist should get together to decide.

Covering of canals

Covering the irrigation ditches would shut out sunlight and eliminate most aquatic growth, but would not prevent the growth of certain aquatic fungi, bacteria and invertebrates. It would, however, be an efficient deterrent to the establishment of snail colonies. From the standpoint of weed control this measure would not be justified as cheaper methods are available. Because of the usual width of laterals, a canal cover would require a strong, probably reinforced, structure in addition to substantial foundations. The cost of constructing and maintaining such a covering and its related structures (foundations, manholes, etc.) tends to rule out this kind of measure from serious consideration.

Piping

The use of pipes, especially concrete pipes, for the conveyance of irrigation water is finding increasing favour in certain countries. In the USA, for example, there are several thousand miles of concrete pipe now in use in California for distributing irrigation water. Most of these are low-pressure pipelines in which the pressure head does not exceed 20 feet (6 m) of water.

Pipe systems have very small transportation losses due to leakage and evaporation, allow more land to be irrigated than do open lateral systems and have lower maintenance and operational costs. It has been estimated that, in the Nile Delta, as much as 7% of the arable land is taken up by rights-of-way, canals and drains. Pipe systems also eliminate weeds as well as insect and snail-breeding problems.

The limitations of such systems are: they are less satisfactory when larger flows are required; their initial cost is high; it is inadvisable to use concrete pipes in saline or alkaline soils; they occasionally need special repairs. A special disadvantage cited by W. H. Wright (personal communication to WHO, 1955) is the infestation of pipes in the USA with a clam, *Cyclas fluminea* (Müller), which seriously impedes water delivery and the operation of valves and of laterals and sprinkler systems. It is understood, he said, that clams of this genus are widely distributed and that *C. fluminea* was introduced into the country from China. Their presence in pipes has also been reported from Egypt. Possibly, similar objectionable features of pipe systems have been noted or will be noted in the future.

A question raised by J. Gaud in Morocco and J. O. Buxell in Egypt (personal communications to WHO, 1955) relates to how acceptable the piped system of irrigation is to the rural folk in countries where bilharziasis is prevalent. Both Gaud and Buxell pointed out the importance of the ethnological factors involved in the use of the open canal systems and the fact that such systems are fully integrated into the education and the economic and labour equilibrium of the rural population. Gaud expressed the need for active health-education campaigns in connexion with the installation of pipe systems.

The closed or high-pressure system, commonly used for the distribution of domestic water, is rarely designed for irrigation service. Such a system requires that pipe shells be strongly reinforced, which increases costs considerably.

" Open " systems, which are in somewhat more general use, are characterized by an overflow stand at periodic intervals. Deliveries of water are made from the upstream portion of each stand. These systems are known to possess the inherent instability associated with the " entrainment " of air.

Semi-closed pipe systems are receiving increasing attention in the USA, North Africa and elsewhere. They are believed by many to be superior to other systems in operating characteristics. Experiments carried out at the University of California by A. F. Pillsbury and E. H. Taylor indicate that the semi-closed system has the essential operating characteristics of the closed system except that pipeline pressures never exceed the value established by the water surface in the next stand upstream. It is therefore possible to use low-pressure pipe. F. M. Stead (personal communication to WHO, 1956) believes that the semi-closed systems hold considerable promise and are to be encouraged from the standpoint of mosquito control.

Apparently, the features of all pipe systems would make them very suitable for snail control as well as for mosquito control. In addition, the planning of such systems might take into consideration the provision of a supply of raw water for rural communities and individual farmhouses located along the pipe route. Such a water-supply would, of course, require purification in order to make it potable. The provision of silt traps at suitable places would take care of the silt problem. From the standpoint of both health and engineering, irrigation by means of piped lateral distribution systems deserves further study by workers in the field.

Drainage

Drainage of an irrigation system is effected by means of open ditches or underground tile-drains. In the latter case, there can obviously be no snail growth, but the problem may be extremely serious in open drains. Such ditches often serve very flat areas, so that their slopes and the velocity of flow are very small. Drainage flow includes not only excess irrigation water but also normal surface run-off, the determination of which forms the basis for drainage design.

As in the case of irrigation canals, the lining of open drains would be beneficial for snail and mosquito control.

While it may not be economical to line open drains completely, it is perhaps advisable to provide them at least with lined inverts (prefabricated concrete inverts, for example), which would have the advantage of concentrating small flows and of increasing water velocity.

Drainage is also recommended to dry up swampy land where disease-carrying snails constitute a serious public health hazard. If, however, the open drains used for this purpose are not designed and constructed in an appropriate manner by the engineer, the swamp may be well drained but the snails may simply shift their habitat to the drains, thus spreading the disease over a wider territory than before.

Other measures

Other measures within the purview of the engineer include the proper supervision and regulation of irrigation systems to prevent overflow and excess water, the proper maintenance of all structures and the elimination of water pools and dead corners at the inlet or outlet ends of culverts, canal crossings, etc.

The Role of Environmental Sanitation

The presence of vector species of snails in irrigation systems would not constitute a public health hazard if these systems were not contaminated by man through faeces and urine. The safe disposal of these human wastes is an important aspect of all bilharziasis campaigns and involves the application of engineering measures. These measures, however, belong to the realm of rural sanitation and are within the competence of the public health engineer and the sanitarian. They are outside the scope of this paper. Mention should also be made of vector control by means of molluscicides, which also falls within the realm of environmental sanitation.

WHO is giving much attention to the study and development of sanitation, including vector-control measures applicable in bilharziasis-affected areas. Two monographs on the subjects of water supply and excreta disposal, respectively, for rural areas and small communities are now in preparation. As to vector control, WHO (1956) has published specifications for molluscicides, and through its Expert Committee on Insecticides (1956) has recommended methods and equipment for their application.

Economic Analysis of Engineering Control Measures

The brief review given above indicates that, for irrigation systems, two of the most effective measures against snails, insects and other disease-bearing organisms are probably the lining (hard-surface type) of canals and the provision of pipes in lieu of secondary and tertiary open earth canals. The initial costs of these measures are undoubtedly high. In the case of canal lining, the Bureau of Reclamation of the US Department of the Interior (1952) has conducted studies on the cost and efficiency of lined *versus* unlined canals, as well as an investigation of types of lining. These investigations show that, leaving aside preventive medicine considerations, it is frequently possible to justify the adoption of a lining programme simply on the grounds of the tangible benefits that will be derived from it. In areas where bilharziasis, malaria and water-borne disease add up to form a serious public health problem, it is desirable to assign a monetary value to the intangible benefits which will accrue from a reduction in these diseases, in order to make the lining programme economically feasible. To show economic feasibility, the capitalized annual value of the benefits (both tangible and intangible) resulting from the installation of lining must be equal to, or greater than, the annual cost of the lining. In order to make this calculation, the engineer needs to collect a considerable amount of data, some of which must be furnished by the public health department. The maximum cost of lining permissible under a given set of conditions may be determined from the following formula:

$$C = \frac{Y}{TL}\left[\frac{LnW\,(ps - PS)}{43560} + a + A + M\right], \text{ where}$$

C = cost of lining, completed, in cents (US) per square foot
s = seepage loss in unlined canal (cubic feet per square foot per 24 hours)
S = seepage loss in lined canal (cubic feet per square foot per 24 hours)
p = wetted perimeter of unlined canal (feet)
P = wetted perimeter of lined canal (feet)
T = total perimeter of lining (feet)
n = number of 24-hour days which canal operates annually
W = value of water (cents per acre* foot)
L = length of canal (feet)
Y = life of lining (years)
a = value (cents per year) of tangible lining benefits, other than value of water saved and savings in operational and maintenance costs, for length of canal considered. (Include here value of land saved from seepage.)
A = total value (cents per year) of intangible lining benefits, such as reduced costs and insurance against failure, for length of canal considered; reduced cost of medical care and drugs otherwise necessary for treatment of bilharziasis and other relevant diseases; increased potential for productivity of population protected, etc.
N = annual savings (cents) in operational and maintenance costs, due to lining, for the length of canal considered

* One acre = 43 560 square feet

Such a formula may be adapted for use in other countries than the USA. It is important to note that, in most regions of the world, costs will not be comparable with those in the USA and that it will be necessary in each case to determine the economic feasibility of improving irrigation systems in the manner desired by all concerned. Similar investigations are needed with respect to both canal lining and pipe systems of irrigation.

Need for Research

In this paper, a review has been made of some of the well-known features of irrigation systems which can play a part in the fight against bilharziasis and other diseases. We believe that there are other engineering devices which may also be employed, perhaps in modified form, when further advances have been made in the study of snail ecology. Before applying engineering control measures, the engineer needs guidance from the malacologist and the epidemiologist. It would appear exceedingly worth while at this time for such a three-man team to undertake, in every bilharziasis endemic area, experimental work which would lead to the determination of the precise character and extent of the relationship between irrigation engineering and bilharziasis. From such studies it might be possible to evolve practical modifications of current irrigation techniques which, while they might not provide the complete answer to bilharziasis control, might be useful, and possibly more effective than any methods now available. The likelihood of such a finding is considerable if proper experimental facilities and pilot studies are organized.

Among the problems to be studied, we might mention:

(*a*) study of the precise role played by velocity of flow in canals in preventing the establishment of snail colonies under a given set of environmental factors;

(*b*) influence of the shape and depth of canals on the establishment and multiplication of snails;

(*c*) influence of light and water turbidity on the survival of snails in irrigation channels;

(*d*) improvement of irrigation canal design, to make it possible to observe a given minimum velocity of flow under any operating conditions;

(*e*) study in a given situation of an economical and practical method for the hard-surface lining of irrigation laterals;

(*f*) study in a given situation of an economical and practical piping or aqueduct-type distribution system for irrigation laterals;

(*g*) improvement of intake design, to prevent the entrance of disease-bearing snails into irrigation systems.

The Role of WHO

Methods of controlling bilharziasis have been under consideration for some time in WHO, especially in the WHO Regional Office for the Eastern Mediterranean, whose former Director, Dr Aly T. Shousha, is himself an expert on the subject (Shousha, 1949). During the past seven years, WHO has been guided by the recommendations of the Joint OIHP/WHO Study-Group on Bilharziasis in Africa (1950) and of the WHO Expert Committee on Bilharziasis (1953).

Recently, upon request from governments, consultants and teams of specialists including public health engineers have been operating in Egypt, Syria, Iraq and the Philippines. At the present time, the bilharziasis control project in Egypt is being redefined to include a plan for making an engineering review of Egyptian irrigation system design, construction and operation; it is proposed, in the light of this review, to set up pilot studies of modifications, so as to determine practical ways of reducing bilharziasis transmission brought about by the irrigation system. Assistance has also been requested by the Government of the Sudan, where some experiments are under way on the effect of village siting, in relation to irrigation canals and drains, on bilharziasis transmission.

WHO is now making plans to assist the University of Alexandria, in collaboration with the International Co-operation Administration of the United States Government, to include some applied research or experimental investigations on this subject in the projected work programme for the Sanitary Engineering Experiment Stations and the Higher Institute of Public Health, now under construction in Alexandria, Egypt.

In addition to these activities, WHO might be able to stimulate an awareness of the need for immediate and effective collaboration between the health and irrigation departments of governments in affected countries. WHO might also wish to help more governments and institutions to carry out experimental studies on, and scientific appraisals of, improved design of irrigation systems for bilharziasis control, by providing engineering consultants. WHO might foster the introduction into the engineering curriculum of civil engineering schools in bilharziasis-affected countries of lectures on the subject of the health implications of irrigation schemes, including bilharziasis control. In this connexion, short courses might be arranged for civil and irrigation engineers from such countries on a regional or inter-regional basis under the sponsorship of the Organization. Finally, WHO might arrange for a seminar on the subject to be held in perhaps two to three years time.

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RÉSUMÉ

Un groupe d'étude OIHP/OMS sur la bilharziose a attiré, en 1950, l'attention des gouvernements sur les dangers que représente pour la santé publique la propagation de la bilharziose par les systèmes d'irrigation. En 1953 ce fut le tour du Comité d'experts de la Bilharziose de noter que les conseils donnés en 1950 n'avaient pas encore été suivis et que, dans bien des régions, il n'existait pas de coopération entre les services de santé et les autorités chargées de l'irrigation. Le Comité recommanda que, parmi les mesures envisagées pour améliorer l'efficacité de la lutte contre les mollusques vecteurs de la maladie, une attention toute spéciale soit attachée au contrôle du milieu écologique, c'est-à-dire au drainage, à l'irrigation, au désherbage, aux pratiques agricoles et à l'assainissement.

L'importance de ce problème a été démontrée en Egypte où, dans certains districts, le taux de la population atteinte est passé de moins de 10% à 75% en trois ans, après l'introduction de nouveaux systèmes d'irrigation, destinés pourtant à élever le niveau économique de ces régions. Des cas similaires ont été rapportés dans de nombreux pays d'Afrique, du Moyen-Orient, du Pacifique et de l'Amérique du Sud.

L'ingénieur chargé de l'irrigation a été souvent accusé par les autorités sanitaires d'être le responsable de cet état de choses. Ses préoccupations majeures consistent, d'abord, à irriguer les terres de la façon la plus efficace et la plus économique possible et, ensuite, à évacuer tout excédent d'eau superficielle ou toute eau souterraine qui pourrait boucher les pores de la couche arable et causer ainsi un excès de minéralisation du sol. Ces travaux sont souvent la condition *sine qua non* du progrès agricole, et il s'y adonne avec la plus grande ardeur, perdant parfois de vue le fait que ces mêmes travaux peuvent répandre la maladie et l'incapacité physique en lieu et place du bien-être économique.

Les principaux éléments de calcul dont il faut tenir compte dans la construction des canaux d'irrigation sont la vitesse de l'eau, la section et la profondeur du canal, ainsi que les pertes du liquide le long des conduits. La vitesse permise dépend de nombreux facteurs, tout particulièrement de la pente du canal et de l'érosion de ses parois, mais la vitesse la plus économique est celle qui conduit à la plus petite dimension de canal et au moindre coût de construction, tout en empêchant le dépôt de sédiments. La vitesse moyenne se produit à la moitié environ de la profondeur d'eau, tandis qu'au fond du canal et sur les parois, où se rencontrent le plus souvent les mollusques, la vitesse marginale est beaucoup plus faible à cause du frottement, de la végétation, de la nature de la surface intérieure du canal, mais aussi à cause de sa forme. La forme idéale pour l'irrigation est celle d'un trapèze enveloppant un demi-cercle et dont les côtés font un angle de 60° avec l'horizontale. Cette inclinaison est beaucoup trop grande pour les canaux en terre. Cependant, la forme qui permettrait de maintenir la plus grande vitesse d'eau partout dans le canal est la section rectangulaire, donc parois verticales, qui exige le plus souvent un revêtement

solide. Ce dernier est nécessaire aussi pour empêcher les pertes d'eau dans la traversée de terrains perméables ou fissurés. Dans les deux cas, le revêtement entraîne une augmentation sensible du coût de la construction.

On a souvent remarqué que les mollusques n'arrivent pas à se maintenir et à se multiplier dans des canaux bien entretenus et dotés d'un courant rapide. Les vitesses minimums, pour différentes espèces de mollusques n'ont pas encore été déterminées, mais il semble bien que, dans de nombreux cas, cette vitesse puisse être supérieure à la vitesse économique dont il vient d'être question. En ce qui concerne le revêtement des canaux, les autorités sanitaires et les ingénieurs d'irrigation s'accordent à en reconnaître les avantages malgré leur coût initial élevé. Un revêtement imperméable réduit la végétation aquatique et le plancton qui sert d'appui et de nourriture aux mollusques, permet une augmentation du mouvement de l'eau et une diminution sensible des dimensions du canal.

Parmi les espèces de mollusques vecteurs repérés dans les systèmes d'irrigation, on cite: *Planorbis boissyi, Bulinus truncatus, Biomphalaria pfeifferi, Oncomelania nosophora* et *Australobis glabratus*. Des espèces semblent préférer certaines parties du système d'irrigation, les réservoirs par exemple; d'autres se multiplient plutôt dans les canaux secondaires et tertiaires, où la vitesse de l'eau est réduite et la végétation abondante. Dans les canaux secs à revêtement imperméable, les mollusques et leurs œufs périssent sous l'action du soleil et de la chaleur, tandis que dans les canaux en terre dépourvus d'eau les adultes trouvent souvent refuge dans les crevasses ou dans la terre encore humide du fond et s'y maintiennent jusqu'au prochain cycle d'arrosage. La teneur de l'eau d'irrigation en sels et en gaz carbonique a aussi une grande influence sur le développement des mollusques. Il semble bien que, d'une façon générale, l'eau qui possède une composition chimique satisfaisante pour l'arrosage des cultures et des terres convient aux mollusques.

Une coopération étroite entre l'ingénieur et l'autorité sanitaire dans la lutte contre la bilharziose s'impose donc. Le moyen le plus efficace d'y parvenir serait d'incorporer un ingénieur à l'équipe chargée d'organiser et d'exécuter des programmes sanitaires dans ce domaine. L'ingénieur sanitaire, dont la formation de base est le génie civil, serait d'un immense secours en assurant la liaison entre les services responsables des plans et de l'exécution des travaux d'irrigation d'une part, et ses collègues de la santé publique de l'autre. Les mesures que l'ingénieur pourrait préconiser ne sont pas encore toutes connues à ce jour. En effet, il reste beaucoup à étudier dans l'écologie des mollusques vecteurs et dans la lutte pratique contre ces derniers. Cependant, il n'y a pas de temps à perdre et de nombreux éléments sont déjà à la disposition de l'ingénieur, parmi lesquels on peut citer: 1) les mesures applicables aux réservoirs artificiels, telles que désherbage, augmentation de la profondeur d'eau au pied des berges, et fluctuations des plans d'eau; 2) les mesures applicables aux canaux, telles que nettoyage, élimination des courbes inutiles, chasses d'eau, revêtements solides, imperméables et économiques à la longue; 3) le remplacement des canaux à ciel ouvert par des tuyaux; 4) le drainage, tout en prenant soin de ne pas créer de nouveaux gîtes.

Dans toute campagne contre la bilharziose, on ne doit pas négliger les mesures fondamentales — telles qu'aménagement de latrines et approvisionnement en eau potable — qui permettront de prévenir la pollution de l'eau d'irrigation par les déchets humains des porteurs de parasites et de réduire le contact dangereux entre l'homme sain et l'eau infestée de cercaires. L'application de molluscicides efficaces et économiques est aussi à envisager.

Enfin, il faudrait entreprendre des recherches sur le terrain de façon à déterminer le caractère précis et l'étendue des relations qui existent entre l'irrigation et la bilharziose. D'après les résultats de ces recherches, il serait possible d'envisager les modifications à apporter à la conception des systèmes d'irrigation en vue de les rendre, autant que possible, impropres à la vie et la multiplication des mollusques vecteurs de la bilharziose.

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